The Second meeting of the Challenger Society
Special Interest Group on Ocean Wind Waves.

High Impact Waves and Extreme Events

19th & 20th October 2016
HR Wallingford Oxfordshire

Book of Abstracts

Venue

The meeting will be taking place in the Fountain conference centre, on Howbery park. A link in Google Maps can be found here http://goo.gl/maps/AqlZM.

Meals and refreshments

A sandwich lunch will be provided on the Tuesday before the meeting begins. We always ensure that a vegetarian option is available during refreshment breaks. However, if you have other specific dietary requirements, please advise us in advance and we will do our best to accommodate your needs

Evening meal

We are arranging an evening meal at a local restaurant in Wallingford on the evening of Wednesday 19th October, 7pm. Further information about how to find the restaurant will be given to you on the day. We have selected a 3 course set menu for £20. If you would like to attend the meal, you will need to register, and send your menu choice to training@hrwallingford.com by Thursday 13 October.

Health and safety

We ask that if you wish to attend the physical modelling hall that you wear flat, sensible, closed in shoes. You may also want to bring a coat as it can get quite cold at this time of year. We cannot permit you to take any photos inside the modelling hall.

Timetable

12:30* – Welcome and lunch *registration will open at midday

Session 1 Observing Extreme Waves - chair Lucy Bricheno

13:30 – 14:00	Terry Edwards	Wave Observations – Equipment, Applications and Methods
14:00 – 14:15	Christine Gommenginger	Wind, waves and currents from space: past, present, future
14:15 – 14:30	Kieran Newman	Determining Tidal Phase Differences from X-Band Radar Images of Wave Fields
14:30 – 14:45	Lucy Wyatt	Using HF radar for storm surge monitoring
14:45 – 15:00	E.Pugliese Carratelli	Estimating extreme significant wave heights by integrating model and wavemeter data

Tea break and discussion

Session 2 Forecasting Extreme Waves - chair Doug Cresswell

15:30 – 16:00	Jean Bidlot	Progress and limitation in ocean wave forecasting
16:00 – 16:15	Andy Saulter	Application of a refined resolution global wave forecast model
16:15 – 16:30	Huw Lewis	An evaluation of wave predictions with varying ocean and atmosphere coupling at high resolution
16:30 – 16:45	Lucy Bricheno	Future wave conditions of North West Europe, in response to high-end climate change scenarios
16:45 – 17:00	Øyvind Breivik	Projected changes in significant wave height towards the end of the 21st century in the Northeast Atlantic

17:00 – 17:30 – Tour of HR Wallingford Physical models
19:00 – optional evening meal at Avanti, Wallingford

Session 3 Impacts of Extreme Waves - chair Christine Gommenginger

09:15 – 09:45	Judith Wolf	The Perfect Storm: Exploring wave climate projections and the upper limit of coastal flooding for the UK
09:45 – 10:00	Thomas Adcock	On non-linear changes to the shape of extreme wave-groups in deep water
10:00 – 10:15	David Williams	A French Meteotsunami on 23 June 2016?
10:15 – 10:30	Nigel Tozer	A multivariate extreme value analysis for the design of coastal structures in England.

Coffee break and discussion

Session 4 Freak Waves & Statistics of Extreme Events - chair Nigel Tozer

11:00 – 11:30	Paul Taylor	Giant waves on the open sea - mariners' tall tales or alarming fact?
11:30 – 11:45	Doug Cresswell	Storm peak validation and analysis of uncertainty in estimates of extreme sea states
11:45 – 12:00	Nicolas Bruneau	Stochastic extreme waves in the Caspian Sea
12:00 – 12:15	Suzana Ilic	Rogue wave occurrence in mixed sea states: a laboratory experiment

12:15 Meeting close

Tour of physical models

HR Wallingford operates the most modern and extensive suite of physical modelling facilities available anywhere in the world. We have more than 60 years' experience in the construction and operation of the full range of hydraulic physical models, and more than 25 years experience in the supply of equipment and instrumentation for hydraulic laboratories to institutions and universities throughout the world
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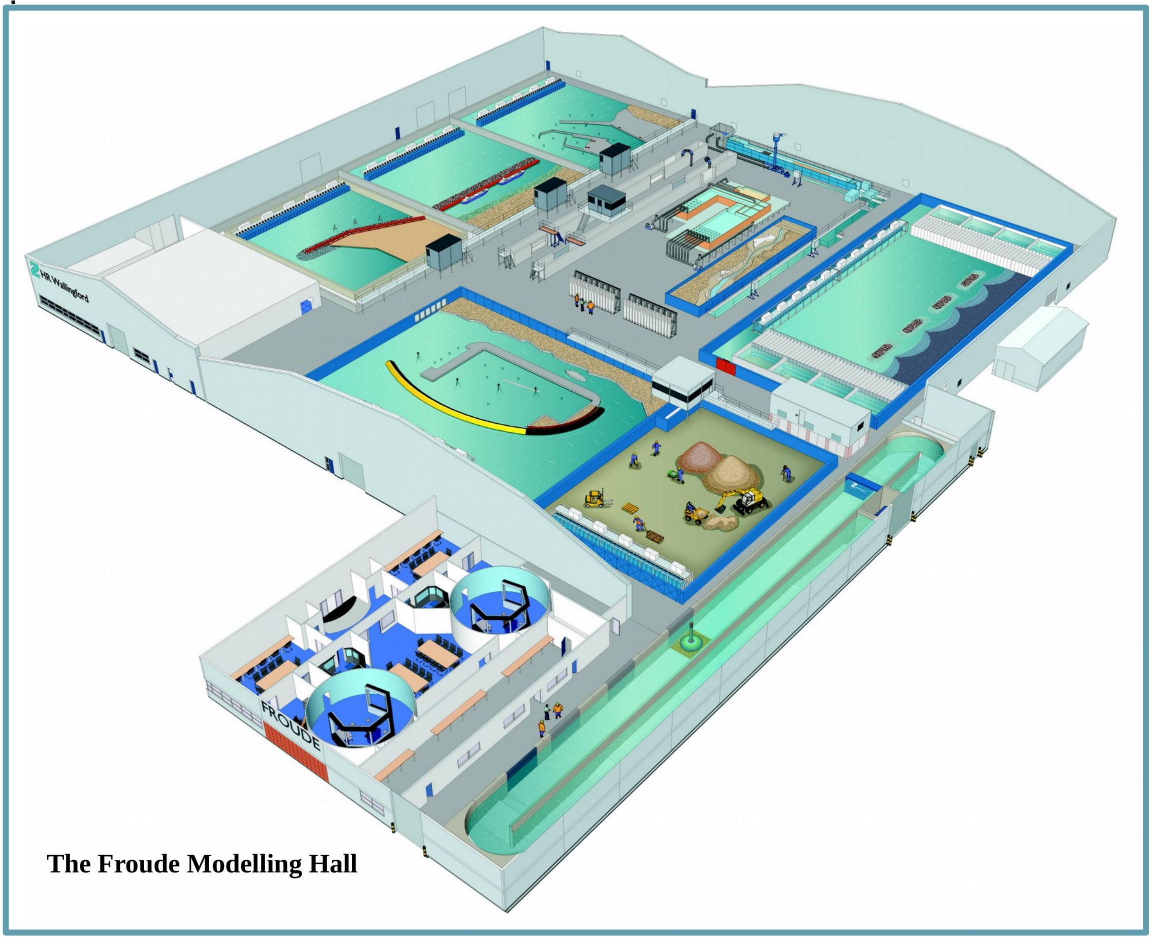


The Froude Modelling Hall

HR Wallingford has undertaken more than 180 physical modelling studies covering the major disciplines of:

- 3D wave and wave/current studies
- 2D wave and wave/current studies
- 3D hydraulic structure (pumping stations, spillways etc) and river flood plain studies
- Specialist testing of tsunami impacts, seabed anchor pullout, performance of flood protection products, aircraft ditching, air in pipelines, fuel tank failures etc.

HR Wallingford's seven wave basins range in plan size from 25 x 32 m to 75 x 32 m and include a 55 x 27 m wave-current basin. Our largest wave basin has a floor area of 2400 m2 and is one of the largest unobstructed hydraulic test tanks in the world. The size of our basins allows major port and harbour developments to be tested without risk of significant scale effects.

Our basins are equipped with state of the art instrumentation including multi-element random wavemakers with active wave absorption, laser scanners, video capture and infrared tracking systems (for monitoring the movement of moored vessels).

About HR Wallingford

HR Wallingford is an independent civil engineering and environmental hydraulics organisation.

We deliver practical solutions to the complex water-related challenges faced by our international clients. With a 65 year track record of achievement, our unique mix of know-how, assets and facilities includes state of the art physical modelling laboratories, a full range of numerical modelling tools and, above all, enthusiastic people with world-renowned skills and expertise.

Based in the UK, HR Wallingford has a reputation for excellence and innovation, which we sustain by re-investing profits from our operations into programmes of strategic research and development.

HR Wallingford reaches clients and partners globally through a network of offices, agents and alliances around the world.

Thomas Adcock

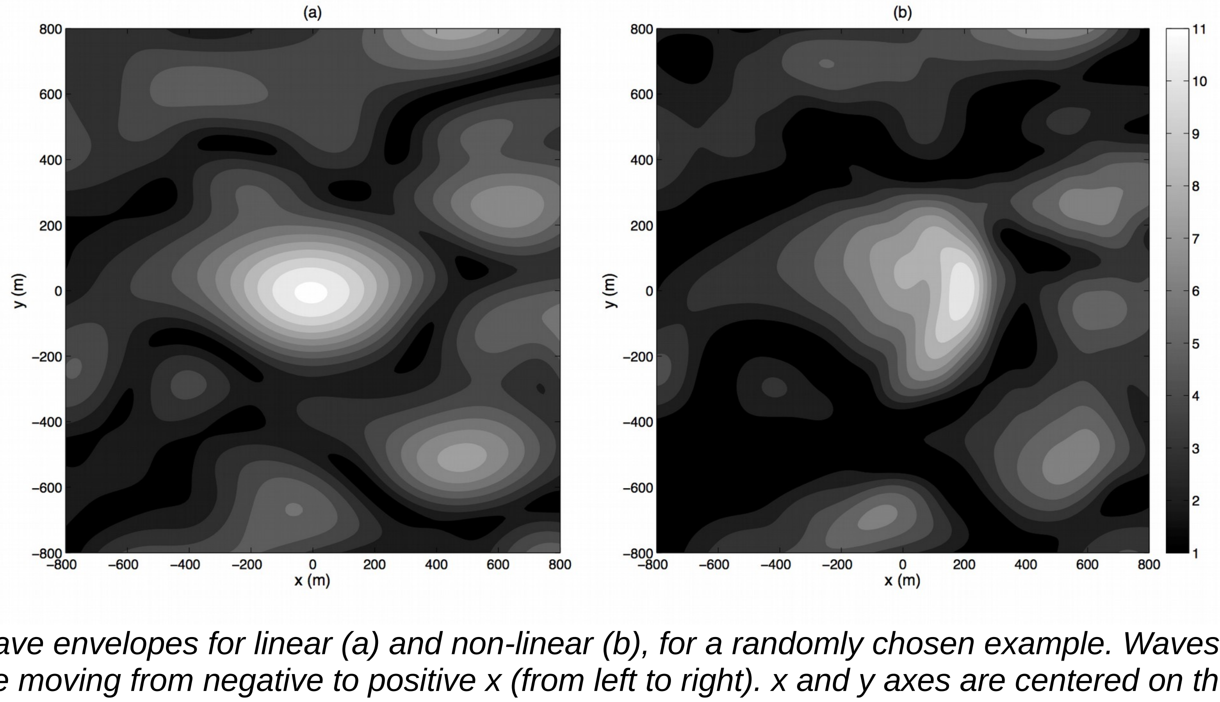
On non-linear changes to the shape of extreme wave-groups in deep water

In this abstract we examine the non-linear changes caused by wave-wave interactions to large waves on deep water using numerical simulations. We use simulations of random linear directionally spread waves to generate our initial conditions. From these linear simulations we extract the sea-surface around a number of large wave events. We run these back in time under linear evolution before running them forward using the broad-banded non-linear Schrodinger equation [1]. We compare the wave-groups in the linear and non-linear cases. A typical result showing the envelope in linear and non-linear cases is shown in the figure. Methods and results are described in detail in [2].

We find that, on average, we only get extra elevation above that expected under linear evolution for low directional spreads. Real ocean waves are directionally spread and it is unlikely that the spectra for which we do see extra amplification would occur in the open ocean. However, for more realistic initial conditions some waves are magnified which may be a concern for offshore engineering design.

Non-linearity can cause a significant change to the aspect ratio of an extreme wave-group, with the group contracting in the mean wave-direction and expanding laterally. However, these are not coupled. The lateral expansion of the wave-group occurs even in relatively mild seas. However, the mean wave direction contraction occurs only for steep sea-states with low directional spreads.

The final non-linear change is that the largest wave within a wave-group will tend to move to the front of the group. This means that for an Eulerian observer in the ocean the wave preceding an extreme wave will usually be relatively small. This effect occurs most dramatically in steep sea-states with low directional spreading.



Wave envelopes for linear (a) and non-linear (b), for a randomly chosen example. Waves are moving from negative to positive x (from left to right). x and y axes are centered on the linear maximum in the wave-field. Envelope elevation is in m.

Jean-Raymond Bidlot

Progress and limitation in ocean wave forecasting

Over the last two decades there have been major improvements in the quality and reliability of weather forecasts. As the quality of the forcing winds got better, so did the wave models that use these wind fields. As more attentions have been paid to describe better the different processes that are involved in the life cycle of waves, it has also been recognised that waves are actively participating in the exchanges between the atmosphere and the oceans. Therefore, to best represent the exchanges at the surface of the oceans, atmospheric models should be tightly coupled to an ocean wave model.

Conversely, progress has been made to include an ocean model as part of operational medium range forecasting systems and to include the ocean waves in the modelling of exchanges between atmosphere and ocean.

Significant progress has therefore been achieved in forecasting extreme sea states. For instance, it will be shown that recent improvements in model physics and increase in resolution have contributed in good forecasts of large waves associated with recent winter storms such as wind storm Gertrude, or with tropical cyclones such as Hurricane Sandy. Even old cases, such as the large waves leading to the famous Draupner freak wave can nowadays be hindcast. One should however use and interpret observations of extreme conditions with care.

Nevertheless, there are still indications that waves associated to certain storm conditions are not always predicted by global models. Work is currently carried to review some of the current parameterisations used to specify the level of momentum, heat and moisture exchanges. Results of sensitivity studies will be discussed.

The prediction of extreme weather depends on many unknown variables. For these reasons, ensemble techniques have been developed to account for these uncertainties. It will be shown that ensemble forecast products are very valuable tool in determining early warning of extreme conditions at sea. Even, the latest reanalyses, currently being produced, will endeavour to produce error estimates.

Lucy Bricheno

Future wave conditions of North West Europe, in response to high-end climate change scenarios

Future wave conditions of North West Europe, in response to high-end climate change scenarios   Coastal areas (less than 100m above sea level) are the most densely populated on earth - currently, more than 35% of the world’s GDP and 40% of the population (e.g. Lichter et al., 2011) is located there. The relevant physical variables which will affect these areas in a warmer future climate are global/regional sea level rise and changes in extreme sea levels, storminess and waves.

Projections of coastal wave impacts under high-end climate change (RCP4.5 and RCP8.5) scenarios have been made, using CMIP5 climate model forcing to drive the WaveWatchIII wave model at global and regional scales. Our particular area of interest is the Atlantic-facing NW European coast. We have used Euro-CORDEX downscaled wind forcing at ~11km resolution as well as EC-Earth global winds for the present day to 2100 period. We have explored the change in storm climate in the North Atlantic over this period and derived the changes in the coastal wave climate in order to estimate impacts of climate change on a European and local scale. There are still uncertainties in the North Atlantic storms generated in the latest climate models and we examine the downscaled forcing data in order to estimate how well extreme winds are reproduced. Changes in the metrics of significant wave height, wave period and direction for different types of coastline are explored and implications for coastal adaptation are assessed.

Øyvind Breivik

Projected changes in significant wave height towards the end of the 21st century in the Northeast Atlantic

Wind field ensembles from six CMIP5 models have been used to force wave model integrations of the Northeast Atlantic for the last three decades of the 20th and 21st centuries. The future wave climate is investigated by considering the RCP4.5 and RCP8.5 emission scenarios. The CMIP5 models are selected based on their ability to recreate the marine wind climate, but increased spatial resolution has also been emphasized. In total, the study comprises 35 model integrations totalling more than 1,000 model years. Here, annual statistics of significant wave height are presented, including mean parameters and upper percentiles. There is general agreement among all models considered that the mean significant wave height is expected to decrease by the end of the 21st century. This signal is statistically significant also for higher percentiles, but less evident for annual maxima. The RCP8.5 scenario yields the strongest reduction in wave height. The exception to this is the north western part of the Norwegian Sea and the Barents Sea, where receding ice cover gives longer fetch and higher waves. However, both RCP4.5 and RCP8.5 scenarios exhibit regionally markedly higher variance than the historical period, making higher extremes more likely even as the mean wave height appears to decrease. This result, when standardized against their historical model climate, is robust across a majority of the CMIP5 wind fields considered in this study.

Nicolas Bruneau

Stochastic extreme waves in the Caspian Sea

Stochastic extreme waves in the Caspian Sea   From a natural disaster point of view, extreme waves in near-shore regions can lead to defence overtopping and breaching, resulting in severe floods threatening human life and property. Recently, much effort has been made to statistically estimate extremes, however generating accurate ensembles of stochastic weather patterns which maintains space and time properties is still a challenging task.

Here we propose a new methodology to estimate extreme wave events in the Caspian Sea. The study is based on 26 years of CFSR winds (1990-2015) and associated waves simulated with the spectral wave model SWAN (Delft University of Technology).

First, 2500 years of continuous wind fields are generated via a stochastic weather generator using a multivariable, multisite PXEOF-EEOF (Periodic and Extended EOFs) model methodology. The stochastic model accurately captures the spatial and temporal variability of the wind climate for the Caspian Sea, particularly the bi-modal wind propagation direction (NW or SE) in the central Caspian Sea region.

Secondly, due to the strong correlations between winds and wave heights (the Caspian Sea being a quasi swell-free environment), the most extreme wind events are selected for each year and the wave characteristics are simulated (with SWAN) in order to compute exceedance probability of different return periods.

Finally, we investigate the discrepancies of significant wave heights and peak wave periods between a direct approach (consisting of "extrapolating" the 26 year of simulated waves) and our stochastic approach which aims to preserve the wave dynamics.

E.Pugliese Carratelli

Estimating extreme significant wave heights by integrating model and wavemeter data

The availability of data generated by global and regional wind and wave model chains (WiWaM) have brought radical changes to the estimation procedures of extreme Significant Wave Heights (SWH) and of their probability distribution, generally described by the SWH/Return Time function SWH(Tr)

WiWaM are routinely run all over the world and SWH time series for each grid point are computed and published after assimilation (analysis) of sea truth data, generally produced by satellite altimetry. Such data are only available at long and irregularly-spaced time intervals, depending on the satellite coverage, so the probability that the assimilation is carried out during an extreme event is low: this reflects badly on the reliability of the highest simulated SWHs and therefore on the quality of the extrapolated SWH(Tr).

Even when good quality wave buoys data are used (as for instance in Sartini et al, 2015) and a reliable SWH(Tr) can be produced for the actual buoy geographical position, there is no guarantee that the results can be extended to other locations in the same region.

The sources of WiWaM data are numerous, but many aspects of the procedures are hidden to the users; thus, in order to provide a simple engineering tool to evaluate the probability of extreme sea-states as well as the quality of its estimate, we propose here a procedure based on integrating model generated $SWH_m(Tr)$ with the $SWH_b(Tr)$ obtained by wavemeters in the same area, in order to produce a calibration oriented towards the extreme values, rather than to their average.

In the examples the Weibull distribution has been used (for details, Dentale et al, 2015); this work however is not aimed at evaluating, discussing or recommending one particular form of SWH(Tr), or any procedure to estimate its parameters: the only requirement is that such form and procedure should be uniform throughout the whole analysis.
We assume thus that for each Tr an estimated value $SWH_{est}(Tr)$ can be obtained as

$$SWH_{est}(Tr) = SWH_m(Tr) + SWH_m(Tr) \quad e(\mu,\sigma) \qquad (1$$

i.e., it is assumed that for each Tr the SWH can be provided by using its modelled value as an estimator, and adding an error proportional to the estimator itself and to a normally distributed relative error $e(\mu,\sigma)$

$$e(\mu,\sigma)= (SWH_{est}(Tr) - SWH_m(Tr))/ SWH_m(Tr) \qquad (2$$

It is further assumed that the $e(\mu,\sigma)$ distribution depends on the local meteorological climate, and can therefore be evaluated by considering the values of e_b computed by making use of the $SWH_b(Tr)$ curves computed with the wavemeter data in the region.
The regional expected value $\mu e(Tr)$ is then

$\mu e(Tr) == [\sum [e_b(Tr)]/N \quad) = [\sum [SWH_b(Tr) - SWH_m(Tr))/ SWH_m(Tr)]/N$, (3

the sum being extend over the N available buoys. Its variance is given by

$Var e(Tr) = \sum(e_b(Tr) - \mu e(Tr))^{2} \quad (N-1)$ (4

and its root mean square $\sigma e(Tr)$

$\sigma e(Tr) = \sqrt{Var e(Tr)}$ (5

Eq. 1 then provides the relationship between SWH and return time from the model value for any point in the area; a confidence interval can also be provided by adding and subtracting $\alpha \sigma e(Tr)$

$SWH_{est}(Tr) = SWH_m(Tr) + SWH_m(Tr)\ e(\mu, б) + \alpha \quad \sigma e(Tr) \quad SWH_m(Tr)$ (1'

Figure 1 shows typical results

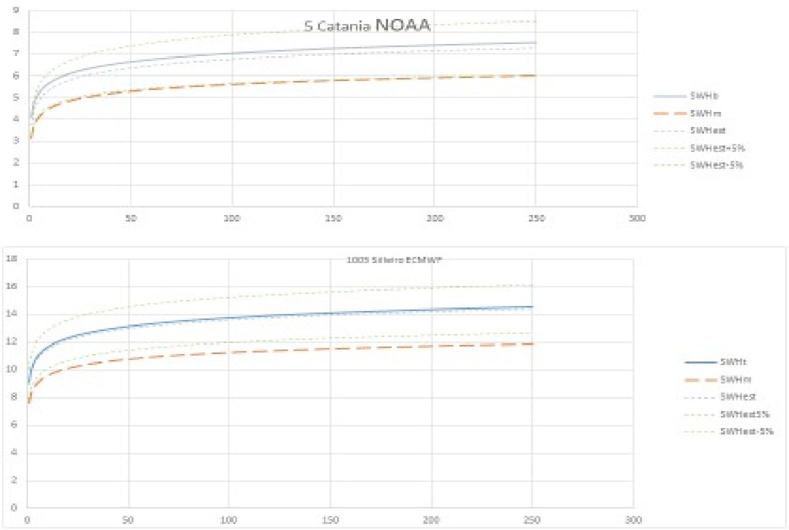


Fig 1: SWH(Tr) Weibull curves at buoy location: SWHt(Tr): buoy value; SWHt(Tr): model value;
SWHest(Tr): estimated with model and local regional error ; SWHest5% (Tr): confidence interval estimated with model and local regional error

Doug Cresswell

Storm peak validation and analysis of uncertainty in estimates of extreme sea states

Storm peaks are often under-estimated in numerical models, as is widely acknowledged. Yet, for many sites where estimates of extreme storm conditions are needed for engineering design, numerical models are the best – if not only – source of information. We discuss uncertainty in estimates of extreme sea states based on numerical model datasets . A method of validation for extreme conditions is presented based on matched pairs of independent storm peak events between modelled time series and buoy based observations, and found to be preferable to exceedance based validation techniques. Systematic biases in the storm peaks of the CFSR, ERA-Interim and NORA10 datasets, when compared to buoy data, are discussed. Sea states at the peaks of storms are compared and contrasted to the general population of sea states. We demonstrate a calibration scheme designed to remove bias from estimated storm peaks using a minimal set of parameters, in order that parameters may be mapped and estimated at sites where no observations are available.

Bias corrected model estimates of storm peaks have a remaining uncertainty associated with model precision. Probability distributions of extreme sea states are estimated using Markov Chain Monte Carlo and Bayesian techniques. Estimates of model precision, based on peak-focussed validation, are used to predict extreme sea states with associated uncertainty representing both model precision and sampling of the long-term distribution. The analysis allows investigation of the relative contribution to estimate uncertainty of model precision and sampling/length of record. Once uncertainty is considered in the estimation of extreme sea states, a contribution to the mean estimate from precision based uncertainty in the source data becomes apparent.

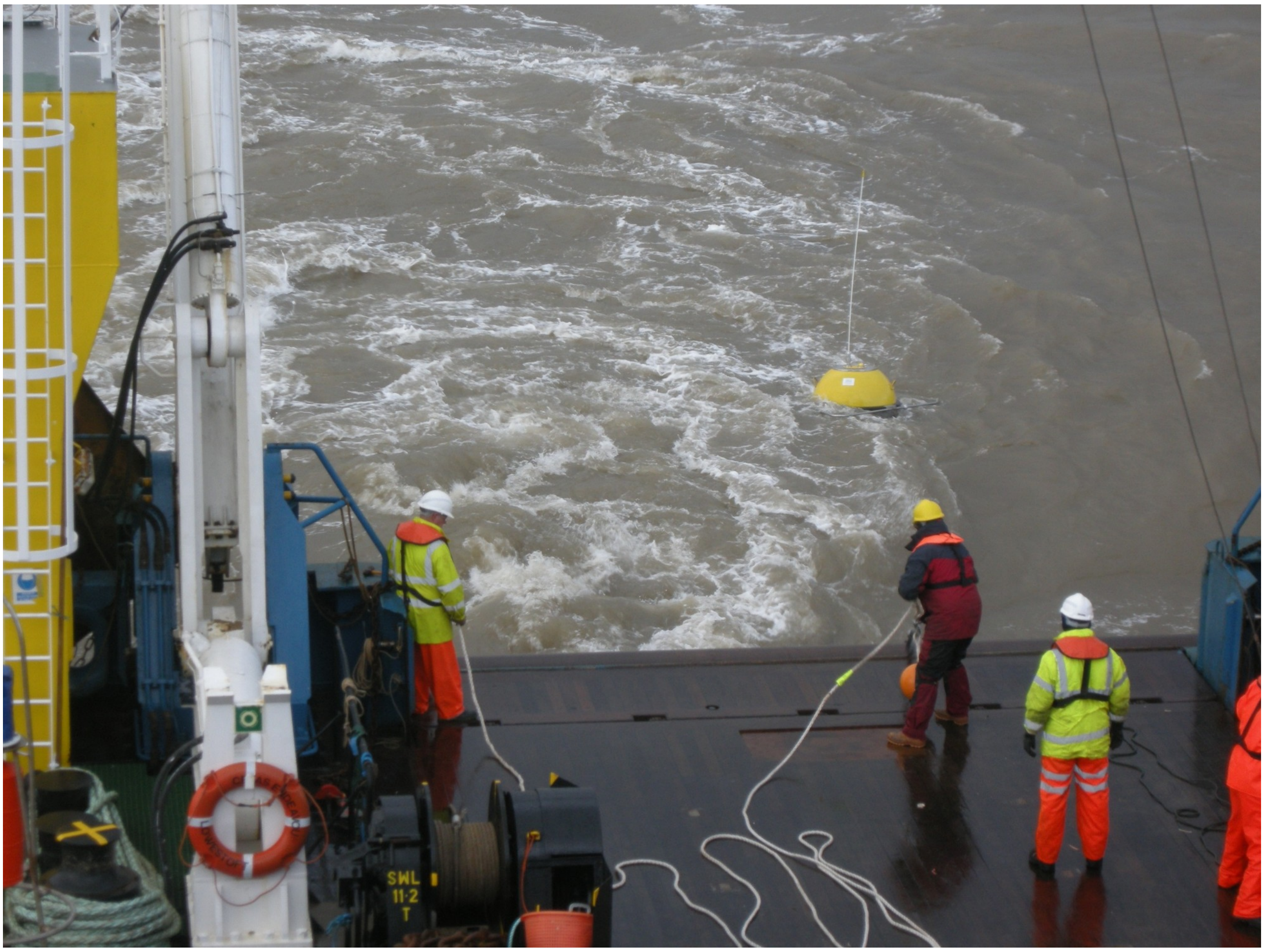
This contribution is also relevant to estimates of extreme conditions based on buoy data with measurement and short-term sampling uncertainties, and provides a baseline level of achievable uncertainty in extreme conditions. Validating uncertainty in estimates requires analysis at a large number of sites, and depends to a great extent on the probability associated with the most extreme events in a series, the so-called plotting position. The formulation of the plotting position has been debated for many years. Numerical experiments are presented that suggest that the correct formulation lies within a narrow subset of the debated schemes.

Terry Edwards

Wave Observations – Equipment, Applications and Methods

Wave observations are made using a diverse range of methods in order to arrive at reliable, robust and meaningful dataset. These methods range from accelerometer based moored systems to seabed fixed pressure recorders and from acoustic Doppler measurements to microwave radar devices, as well as satellite based systems.

The choice of device is dictated by many factors including the application, budget and environment and how the data needs to be disseminated. In this presentation, we will look in some detail at the various devices available, the technology they use, how they have developed and how their suitability can be assessed for a given application. We will also look at where they are used now and how the data are distributed at local and national levels.



Christine Gommenginger

Wind, waves and currents from space: past, present, future

Satellite remote sensing revolutionized our ability to monitor and understand the Earth System by providing observations on a global scale with unprecedented frequency and accuracy. For ocean waves, various techniques already routinely measure wave parameters such as significant wave height, swell period, direction and spectra that are relevant to modelling, forecasting and many other applications. More recently, studies have underlined the potential of satellite measurements to capture the close relation between ocean waves, ocean winds and ocean surface currents and thus enable a more comprehensive characterization of the air-sea interface. New and emerging satellite missions are stimulating new avenues for innovation by offering data so far unavailable in challenging conditions such as hurricanes, dynamic ocean regions and in the coastal zone. The paper will review available information currently available from satellites and present some examples of new remote sensing observations capabilities relevant to wind and wave research.

Suzana Ilic

Rogue wave occurrence in mixed sea states: a laboratory experiment

The occurrence of rogue waves in mixed sea states was studied in wave basin experiments in the MARINTEK laboratory. The overall aim was to understand the factors influencing occurrence and spectral development of rogue waves in bi-modal short-crested seas.The MARINTEK facility is 70 x 50m. Tests were conducted using different degrees of directional spreading and angle of crossing. The water depth was kept at 3m for all tests. Here we report the results of tests investigating the effect of varying separation in peak periods of two crossing sea states.The input spectrum in the frequency domain was composed of two JONSWAP spectra with identical significant wave heights (Hs=0.058m) and peak enhancement factors (γ) equal to 3 and 6 respectively. The directional spreading was set to N=50 and N=200 by using a cosine-type function for wave fields 1 and 2 respectively. The angle between these wave fields was kept constant (40o). The peak period for wave field 1 was set to 1s and for wave field 2 was varying (1s; 1.11s, 1.25 and 1.67s). Four realisations of the random wave field were measured using the same input spectrum with different sets of random amplitudes and phases. There were more than 1300 individual waves in each 20-min time series (more than 5000 in total). Measurements of surface elevation were taken every 5m along the main axis of the basin.Rogue waves were observed in each test, i.e. events with crests larger than or equal to five times the standard deviation or wave heights larger than or equal to twice the significant wave height. The largest overall wave is seen for test with the largest separation in peak periods (1/1.67s), reaching 2.53 Hs. The fourth order moment of the probability density function of the surface elevation, or kurtosis, was well estimated by use of a second-order theory. The separation in peak periods does not appear to exert an influence on the kurtosis. However the spectrum with the largest separation in peak periods showed the least peak down-shift and a slightly faster rate of mean frequency drop-off. A rapid increase in the spectral peakedness was observed down the tank for all four cases with the largest for the separation of 1/1.25s. Close inspection suggests that this may be associated more with the two frequencies converging towards the lower frequency than a narrowing of one frequency peak. Examination of the change in spectral shape and energy down the tank, showed that the energy lost from the higher frequency peak to the lower frequency peak seem to stabilise the lower frequency peak as the separation in peak periods increases. This result agrees well with the work of Masson (1993), who found that when the frequencies of the two components are well separated, the spectral energy is transferred from the high frequency component into the low frequency component, increasing the spectral peakedness and enhancing the occurrence of rogue waves.

Huw Lewis

An evaluation of wave predictions with varying ocean and atmosphere coupling at high resolution

Traditionally, the simulation of regional ocean, wave and atmosphere components of the Earth System have been considered separately, with some information on other components provided by means of boundary or forcing conditions. More recently, the potential value of a more integrated approach, as required for global climate and Earth System prediction, for regional short-term applications has begun to gain increasing research effort. In the UK, this activity is motivated by an understanding that accurate prediction and warning of the impacts of severe weather requires an integrated approach to forecasting. The substantial impacts on individuals, businesses and infrastructure of such events indicate a pressing need to understand better the value that might be delivered through more integrated environmental prediction.

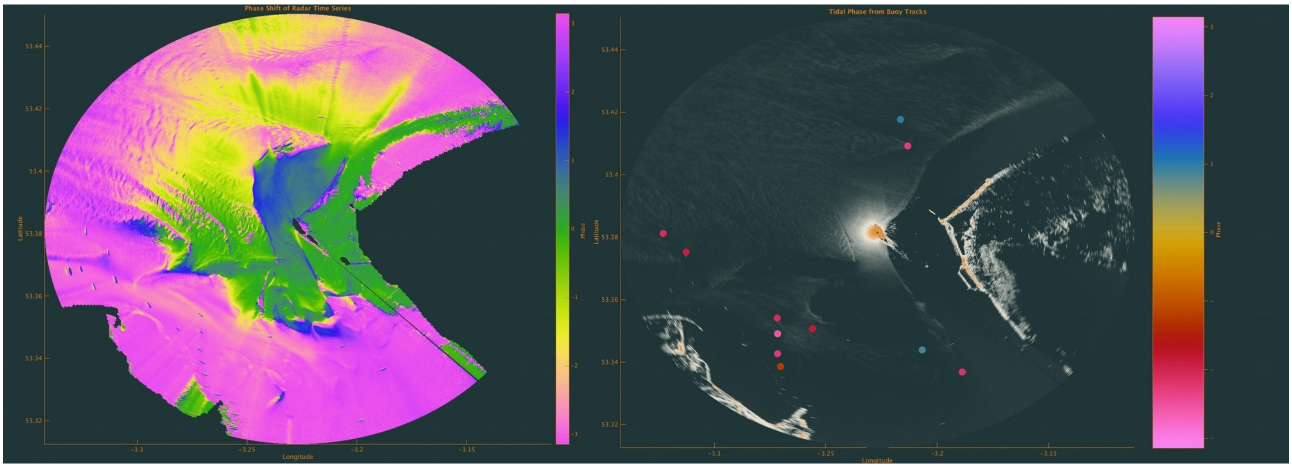
To address this need, the Met Office, National Oceanography Centre, Centre for Ecology & Hydrology and Plymouth Marine Laboratory have begun to develop the foundations of a coupled high resolution probabilistic forecast system for the UK at km-scale. This links together existing model components of the atmosphere, coastal ocean, land surface and hydrology. Our initial focus has been on a 2-year Prototype project to demonstrate the UK coupled prediction concept in research mode.

This presentation will summarise the progress delivered through the Prototype project and focus on new assessment of the benefit of coupling for UK wave prediction at km-scale resolution. By comparing coupled and forced simulations of increasing complexity, we can begin to characterise the impact of feedbacks on wave prediction and improve their representation of observed reality. We will discuss future directions and opportunities for collaboration in environmental prediction, and the challenges to realise the potential of integrated regional coupled forecasting for improving predictions and applications.

Kieran Newman

Determining Tidal Phase Differences from X-Band Radar Images of Wave Fields

Previous work by Bell et. al. (2015) has developed a method using X-band marine radar to measure intertidal bathymetry, using the waterline as a level over a spring-neap tidal cycle. This has been used in the Dee Estuary to give a good representation of the bathymetry in the area. The method relies on accurate knowledge of the water elevation, and assumption of a uniform tidal phase/water level over the domain may be a significant source of inaccuracy. An X-band radar was set up on Hilbre Island, in the Dee Estuary from 2005 to 2009, and an image was recorded at regular intervals using an OceanWaves GmbH Wamos system. Aside from breaking waves at the waterline, and solid objects, the radar will pick up the “sea clutter”, normally filtered or ignored in marine applications. However, this clutter is an indication of the wave field in the scanned area, and can thus be used to measure wave properties. The figure shows the tidal phase computed using two different methods, with data from February 2008, subsampled to 8 images per hour. In the left figure, each raw pixel time series is compared to a tidal signal with a range of phase shifts applied. The phase shift with the highest correlation to the pixel series is then recorded and plotted in the figure. In the right hand figure, the same method of correlation is used, but this time on signal generated by tracking the movement of buoys in the estuary, which show up strongly in the radar image as they move on their moorings. There is obviously some discrepancy between the two methods, so validation is needed to determine the accuracy of each method. Work also needs to be done to separate areas where the recorded phase is due to the tidal current (mostly subtidal areas) or due to the elevation (mostly the wetting/drying signal in intertidal areas). Different data methods such as determining the lag directly from cross-correlation will also be compared, and the method will be run using data from a longer time period. Filtering out signal variations due to wind strength and attenuation of the radar signal will also be applied. Validation will be attempted using data from a POLCOMS run for Liverpool Bay at 180m resolution, and ongoing work to develop a model at 5m resolution using DELFT3D-FLOW. There are also a series of ADCP and other direct measurements of tidal current and elevation, however the periods of measurement do not overlap. However, this could still be used for some validation. While this work is in very early stages, it could present a method to determine fine-scale variations in tidal phase without a network of current recorders, and an improvement in the accuracy of bathymetric methods using X-band Radar.



Andy Saulter

Application of a refined resolution global wave forecast model

In late 2016 (Operational Suite OS38) the Met Office will introduce a new global configuration of its operational wave forecast model. The model is based on WAVEWATCH III version 4.18. The configuration uses a Spherical Multiple-Cell (SMC) grid. This is an unstructured grid, using multiple time-steps for different resolution cells, but retains conventional latitude-longitude grid features, such as rectangular cells and finite difference schemes. Thus it is as efficient as a conventional latitude-longitude grid model at coarse resolutions.

The new global model uses refined cell scales reducing from 25km in the open ocean to up to 3km at the coastline, and source term physics based on the ST4 switch. The choice of a refined grid method has been made in order to improve overall model accuracy (through providing a better description of coastline and island masks) whilst retaining model efficiency, but has the important additional benefit of enabling good quality forecasts to be generated in coastal waters without the requirement to set up and run nested regional models. Adaptations to the WAVEWATCH III post-processing code enable model outputs to be generated in either native grid 'sea-point only' or interpolated regular grid formats.

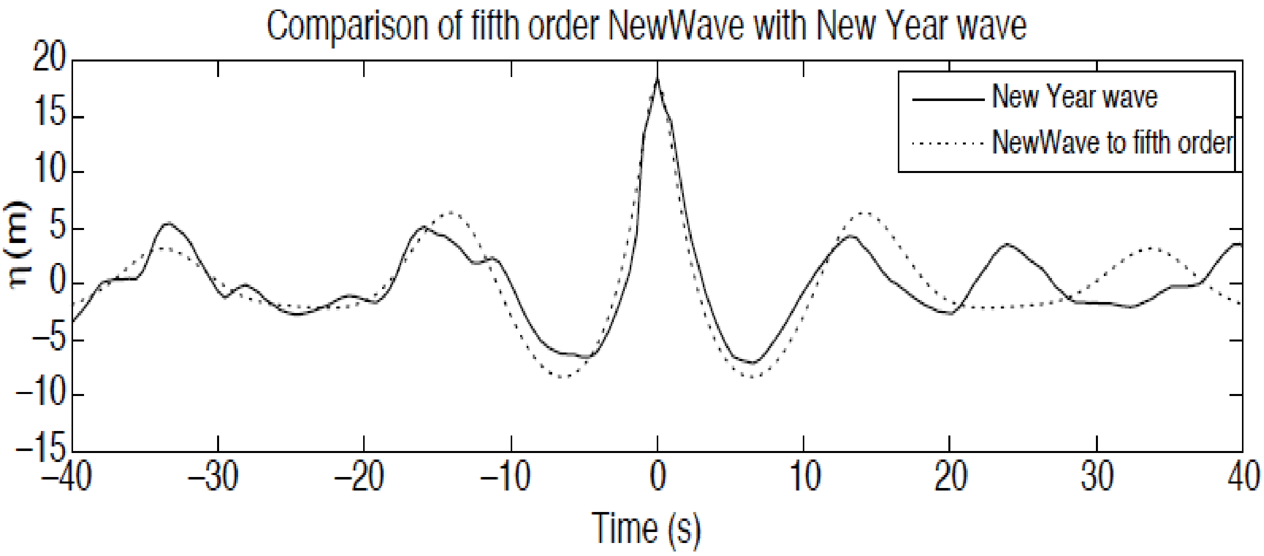
Comparisons between the new configuration and the global model run operationally during the trials period, show a major overall improvement. For example, significant wave height errors were reduced from 18% of the background signal in the operational model to 14% in the new configuration, representing relative change in the errors of over 20%. The model's utility for regional forecasting has also been demonstrated, with more modest improvements in performance also found versus the (8km resolved) European regional wave model. The changes in model quality result from a combination of both the grid and source term updates, with the most notable impact being a reduction in large over-prediction errors during storms.

Layout of 25-12-6-3km SMC wave model cells around the coast of northeast Scotland.

Paul Taylor

Giant waves on the open sea - mariners' tall tales or alarming fact?

It is obvious that storm waves appear random, but is there hidden structure? What is the average shape of the largest waves in a random sea? If waves were linear and random, the answer is simply a scaled version of the auto-correlation function for the surface elevation; this has become known as NewWave in offshore engineering. Previous analysis has shown that large waves driven by severe winter storms in the northern North Sea and hurricanes in the Gulf of Mexico have this simple form, after allowing for the expected vertical crest-trough asymmetry. But these observations were from wave gauges fixed to offshore platforms in relatively deep water. More recent work using data from two Channel Coastal Observatory (CCO) buoys off Cornwall during two large storms in January 2014 shows that NewWave still fits the average shape of large waves, now in relatively shallow water (kd~0.5), and so may have potential for the study of a wide range of wave-driven coastal processes.



Even the famous Draupner wave (above) with a crest well above 18m high in a severe sea-state with H_S ~12m seems to be consistent with a linear NewWave with bound harmonics, at least till one looks a little deeper into its structure: the linear component and sum harmonics seem straightforward but the long wave set-down term tells another story, and suggests possible directional effects.

Nigel Tozer

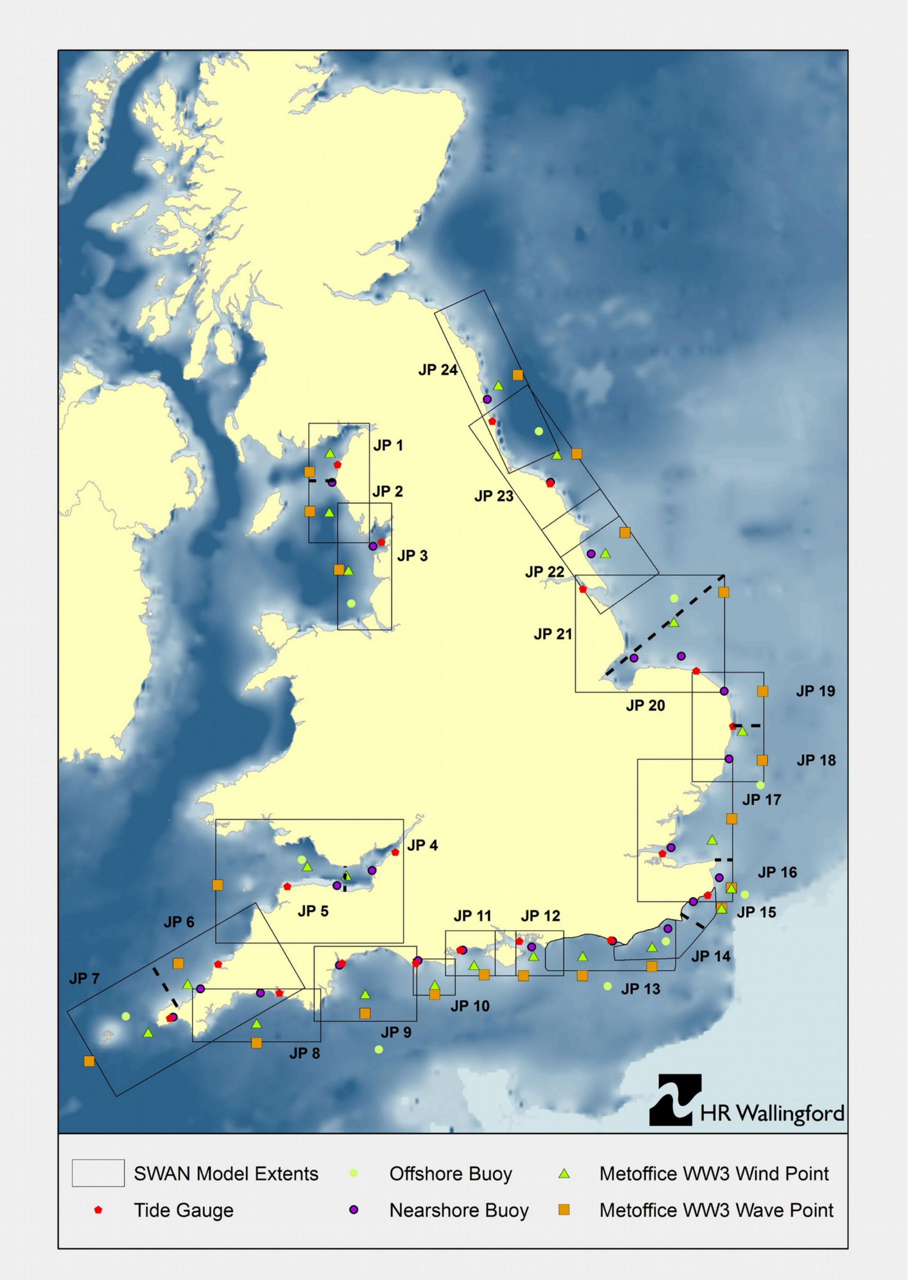
A multivariate extreme value analysis for the design of coastal structures in England.

This paper describes the application of a state-of-the-art multivariate extreme value statistical model to offshore winds, waves and sea levels around the coast of England and Wales. The output of the extreme value statistical model is a Monte-Carlo (MC) simulation of extreme offshore events. To undertake robust risk-based design of coastal structures, it is necessary to assess the performance of existing and proposed new structures against all of these events. A series of SWAN wave transformation models of the coastline have been established, Figure 1. It is, however, computationally impractical to transform all of these MC events from the offshore to the nearshore, particularly when covering the coastline of England and Wales.

A computationally efficient statistical method has therefore been employed. The statistical method, known as an emulator, has been used to replicate the behaviour of the SWAN wave transformation model. The emulators translate the thousands of MC events from offshore to the nearshore. The nearshore results have been stored on a 1km mesh.

This nearshore dataset has the potential to overcome many of the limitations of the existing joint probability methods based on exceedences. The method can be implemented for wide range of uses, including the robust, risk-based, design of coastal structures, climate change impact assessment, nearshore wave climates for detailed local flood risk assessments and coastal flood forecasting.

This paper describes the practical application of the data as developed and applied in the National Flood Risk Assessment – State of the Nation project.



SWAN model grids and data points used in the multivariate extremes analysis

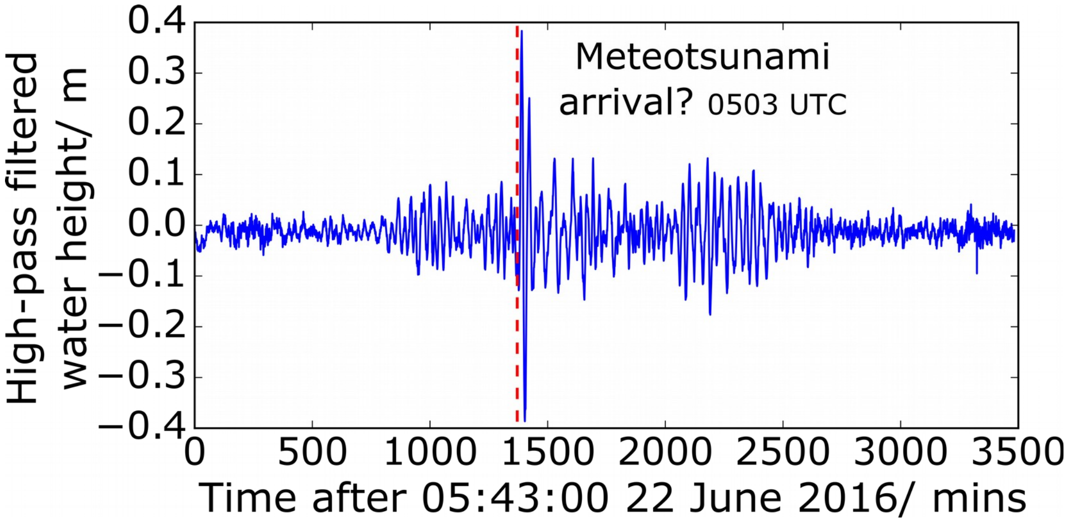
David Williams

A French Meteotsunami on 23 June 2016?

Meteotsunami are surface waves in the tsunami frequency band, with a period of 2 minutes to 2 hours, which are generated by sub-mesoscale atmospheric processes. Though wind stress and the inverted barometer effect only produce an initial perturbation of a few centimetres, multiple amplification factors can cause meteotsunami to grow up to 6 metres. One such mechanism is “Proudman resonance”. This occurs when the atmospheric forcing translates over the sea surface within 10% of the meteotsunami speed. Dependence on this, and other amplification factors, means that meteotsunami are often very spatially limited to sections of coastline. However affected regions are often also prone to repeat occurrences, and in some places they are well known enough to have local names. Given that they are currently unable to be forecast, partly because their physical growth mechanisms are not fully understood, meteotsunami can result in large economic losses and human injury to affected regions.

However due to advances in tide gauge temporal resolution it has become possible to analyse meteotsunami in more detail than was previously possible. It has been found that across Western Europe and Australia strongly convective storms are capable of producing meteotsunami. We give evidence suggesting that a meteotsunami may have occurred on 23rd June 2016 along the northern coastline of France following a strongly convective storm. This evidence includes 1-minute resolution tide gauge data at Boulogne and Dieppe, half-hourly wind velocity data at Le Havre, and MetOffice satellite images. The figure shows tide gauge data from Boulogne after a 5th order high-pass Butterworth filter with a cut-off frequency of 2 hours, indicating a 0.8 m high wave with a period of 32 minutes passed the tide gauge at approximately 0503 UTC (0703 local time).

Furthermore, advances in numerical model spatial resolution have allowed more detailed modelling of meteotsunami. This project uses Telemac, a finite element ocean model, to solve the two-dimensional shallow water equations at high resolutions with low computational expense. This model has previously been proved suitable for seismogenic tsunami models and storm surges. To force Telemac, both highly idealised models of pressure and wind have been used, as well as high resolution numerical models of idealised convective processes in a one-way coupled scheme. We show that our model supports Proudman resonance is possible from a sinusoidal pressure disturbance, and that a numerically modelled convective storm may produce Proudman resonance given suitable bathymetries. This model supports that severe convective storms may have produced a meteotsunami at the French coastline.



Judith Wolf

The Perfect Storm: Exploring wave climate projections and the upper limit of coastal flooding for the UK

Coastal areas (less than 100m above sea level) are the most densely populated on earth - currently, more than 35% of the world's GDP and 40% of the population is located there. They are susceptible to coastal flooding and erosion due to global/regional sea level rise and changes in extreme water levels, storminess and waves. Our particular area of interest is the Atlantic-facing NW European coast, especially the UK. We have accurate coastal impact models of waves and surges for the UK but the main uncertainty in assessing the probability of extreme coastal flooding events in the future is in the occurrence of storms in the atmospheric forcing.

We have a limited sample of observations of actual storm events and an incomplete understanding of the processes causing North Atlantic storm tracks to vary in frequency, direction and intensity. In order to explore the full range of dynamically consistent storms over the UK, to better quantify probabilities of coastal flooding for all locations around the coast, one may use 3 approaches: (i) improve and extend the historical storm database (ii) better understand the characteristics of extreme storms from atmospheric reanalyses (iii) use idealised storms based on these analyses to extend the range of forcing available for impact models.

There are still uncertainties in the North Atlantic storms generated in the latest climate models so we need to examine the downscaled climate model forcing data as well as wind and wave historical reanalyses in order to estimate how well extreme storm winds are reproduced in the historical period and hence how much reliance can be placed on future projections. There seem to be 2 potential mechanisms which may lead to enhanced storm activity over the UK – the warming of the tropics and changes in the Atlantic SST. Waves are an integrator of the effects of wind over the whole Atlantic basin and changes in the metrics of significant wave height, wave period and direction for different types of coastline may have implications for coastal impacts and adaptation, so we need to identify the worst case scenario in terms of the atmospheric forcing and its probability of occurrence. Finally, we ask whether dynamical downscaling provides added value to predictions of extreme waves at the coast.

Lucy R Wyatt

Using HF radar for storm surge monitoring.

HF radars can measure the wave directional spectrum over a wide area at the same time as surface current and wind direction. The combination of these measurements, if available over a wide enough area, would provide very useful input to storm surge prediction models. Local systems can provide input to local warning procedures. In Wyatt et al (2006) we reported on some measurements taken with the Pisces radar during a storm in the Celtic Sea. This was a first attempt to identify features in the measurements that could be used to provide information to be used by authorities on the coast to provide flood warnings associated with storm surges. This work will be reviewed and more recent developments presented.

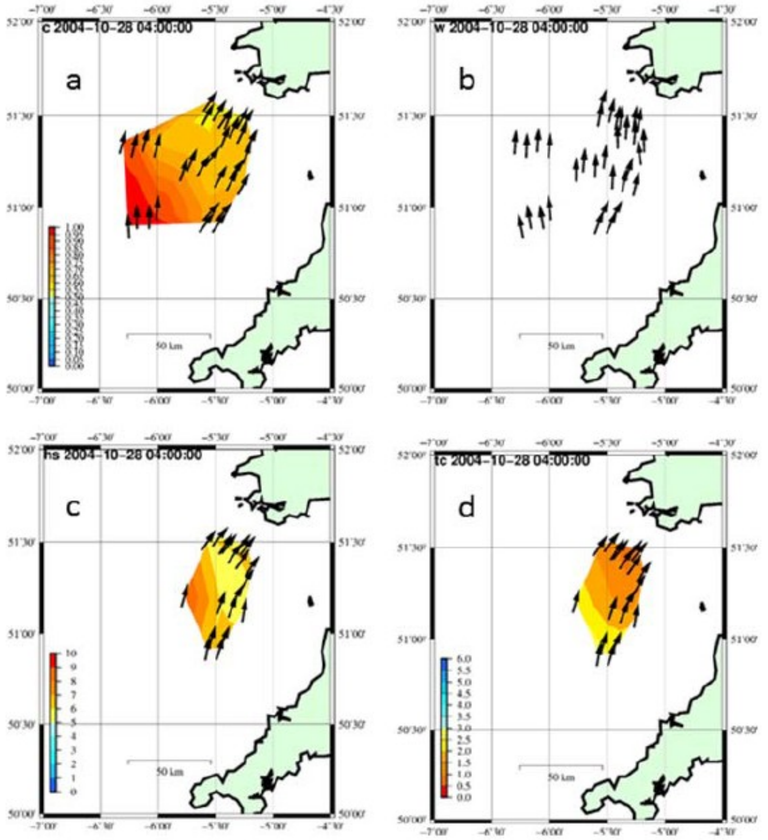


Figure: Maps of (a) surface current, (b) wind direction, (c) significant waveheight and direction, (d) time in hours for wave energy to reach the coast assuming no change in peak direction

Lucy R Wyatt, J Jim Green, A. Middleditch, Mike Moorhead., 2006. Storm surge monitoring with HF radar. European Operational Oceanography: Present and Future. Proceedings of the 4th International Conference on EuroGOOS, June 6-9 2005, Brest, France, published by EuroGOOS Office, 750-754.